

Storage Ring Injection Area Upgrade at the Advanced Photon Source (APS)

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Abstract

Recent machine studies at the Advanced Photon Source (APS) showed that at a beam current of about 140 mA, the storage ring (SR) injection-area components experienced unacceptable elevated temperatures. Heating of these components is related to several factors, namely: aperture discontinuity, poor contact between the rf fingers and the solid sleeve liner, inadequate x-ray shielding, and nonuniform conductive coating on the kicker ceramic chambers. To address these deficiencies, we have developed design upgrades for the injection-area kicker magnets, vacuum chambers, transition absorbers, and bellows-liner assemblies. In this paper, we discuss important features of the new designs and their impact on machine operation at high beam current.

Keywords: storage ring, kicker magnets, ceramic chambers, bellows rf fingers

1. Introduction

The storage ring (SR) at the Advanced Photon Source (APS) operates in top-up mode where beam is injected into the SR every two minutes to maintain an average beam current of 102 mA. Future operating requirements are to have stored beam with an average current of 300 mA. At present some components in the injection area of the storage ring show unacceptable elevated temperature levels when beam current is increased to approximately 140 mA. The components that showed the most significant increase in temperatures were the kicker magnet chambers, the attached bellows with liners, and flanges. An analysis of this problem involved, in part, examining the design of all the components in this section to determine the design changes that would alleviate the overheating and allow us to operate at higher beam currents. On examining ray tracing drawings of this area, we took note that the transition absorbers did not provide adequate protection for some of these bellows and vacuum chambers. Further analysis showed that the sudden change in chamber aperture at some locations and the lack of adequate rf continuity between mating flanges were also contributing factors to localized heating. Another deficiency in the injection area was the inability to constantly monitor the injected beam size and position. It was determined that modifications to the mini-flag and flag chamber would allow for better monitoring of the injected beam.

2. Injection Area

Beam from the booster is injected into the SR via the high-energy transport (HET) line. A thick septum magnet at the end of the HET bends the beam, bringing it close to the stored beam in a parallel trajectory inside the thin septum magnet. Four kicker magnets symmetrically arranged about the injection section are used to bump the stored beam inwards, towards the thin septum during injection [1]. Located between the two kicker

magnets in the injection area are: a fluorescent screen, a section of storage ring vacuum chamber, and the thin septum magnet. Another fluorescent screen, a mini-flag located at the end of the thick septum magnet, is for measuring the injected beam size and position. The vacuum chamber system is made complete with various designs of flexible bellows assemblies joining these components together. The current configuration is shown in Figure 1.

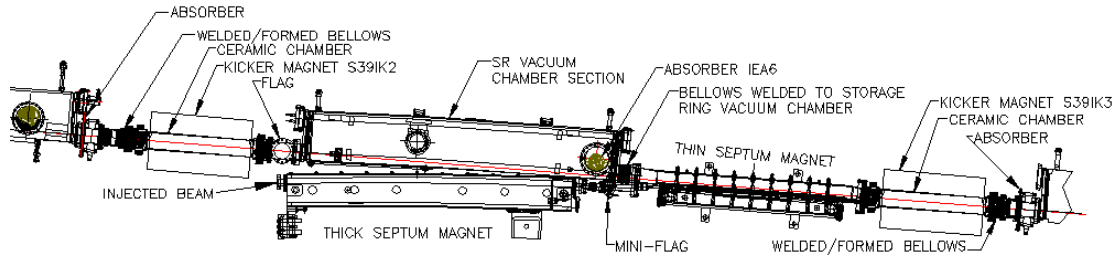


Fig. 1: Layout of SR injection area with existing components.

The existing SR vacuum chamber section was designed with a formed bellows welded to one end. Any leak in this bellows assembly would necessitate replacing the entire vacuum chamber section.

The following changes were made to the injection area and are shown in Figure 2.

- A bellows assembly was designed, detached from the chamber for installation as an independent component.
- Additional single bellows assemblies were designed to replace the arrangements that had separate and adjacent bellows assemblies, where one was of the welded type and the other of the formed type.
- A transition absorber was added immediately upstream of the second kicker magnet (S39IK3), providing more adequate x-ray shielding for the ceramic chamber.
- Several changes were made to the kicker magnets, which are discussed in more detail in section 3.

The physical design of the transition absorbers used in the injection area was not changed. The absorbing material, however, was changed from oxygen-free high-conductance (OFHC) copper to GlidCop AL-15 since GlidCop is more stable at higher temperatures. GlidCop is alumina dispersion strengthened copper, with electrical and thermal properties almost two times better than Beryllium-Copper (Be-Cu), and is resistant to softening due to annealing at temperatures close to the melting point of copper [2]. The elliptical aperture was also reduced by 8.0 mm and 4.0 mm, respectively, on its major and minor axes. This aperture is approximately 17 mm smaller all around than the ceramic vacuum chamber and 12 mm and 16 mm smaller, respectively, on the minor and major axes of the SR vacuum chamber. Based on new ray tracing drawings, this absorber will adequately protect downstream components from x-rays.

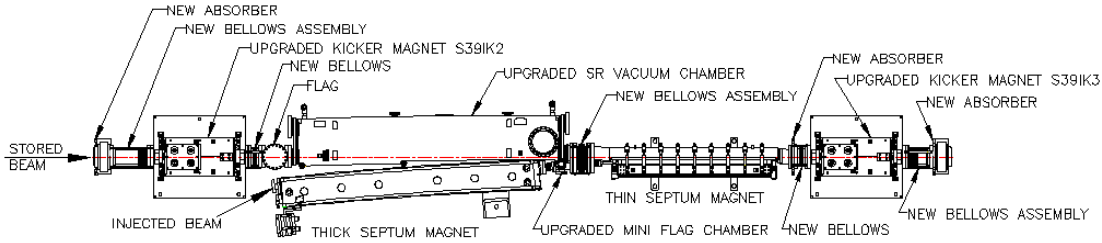


Fig. 2: Layout of SR injection area with new upgraded components.

The fluorescent screen in the existing mini-flag is inserted vertically, which limits its detection of the injected beam within a narrow trajectory. By adding a port to the inside of the arc of the beam trajectory from which the screen is to be inserted horizontally, it would be possible to image the beam at any trajectory.

3. Kicker Magnets

The kicker magnet shown in Figure 3 is typical of the design of all SR kicker magnets having a solid ferrite core, C-shaped in design. When assembled, the ferrite blocks that make up the core create a rectangular aperture in which the vacuum chamber and coils are inserted. The single-turn coil is made in two halves from OFHC copper, insulated with mica tape and an epoxy-potting compound. When assembled, one end of the coils is joined with a copper jumper bar and the other ends connect to the power leads. The ferrite housing is made from G-10 laminate.

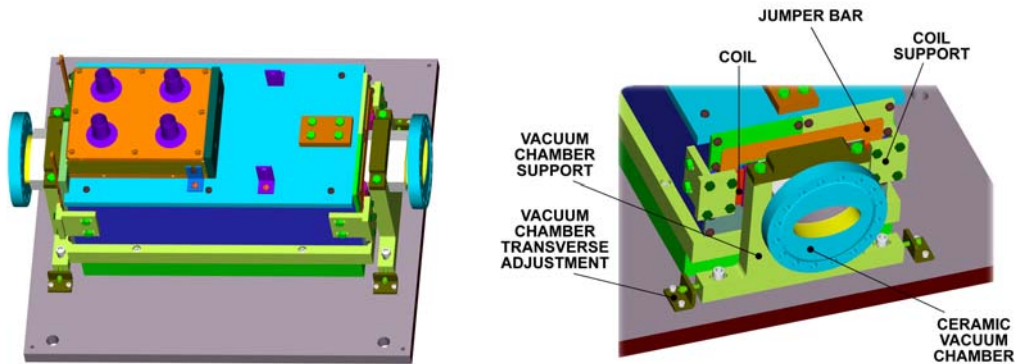


Fig. 3: Assembled storage ring kicker magnet.

The following were some of the guidelines considered in modifying this design.

- All surfaces of the ferrite must be aligned both vertically and horizontally when the magnet is assembled.
- The coil should be centered lengthwise inside the ferrite and held in place since it, along with the ferrite, affects the uniformity of the magnetic field.
- The assembly of these two components should be repeatable when the magnet is installed in the SR.
- The vacuum chamber should be centered within the aperture of the ferrite.

With these guidelines, the ferrite support base was machined to within 0.005-inch flatness tolerance to ensure that all surfaces of the ferrite are in the same vertical plane when assembled. The ferrite was aligned, surveyed, and pinned with 0.125-diameter brass dowel pins allowing for repeatable positioning of the ferrite after reassembly. This was also fiducialized to the base plate to ensure a more accurate placement to the beam orbit when installed in the SR. The ceramic vacuum chamber was independently supported from the ferrite and ferrite housing so that it could be adjusted both vertically and horizontally. Its position was surveyed and locked within 0.003-inch of the ferrite aperture center. L-shaped brackets made in two pieces with slots for adjustment were added to the side of the ferrite housing to support and hold the coil in a fixed position.

3.1 Ceramic Vacuum Chamber

The existing ceramic vacuum chambers shown in Figure 4, were designed with welded-bellows assemblies welded to both ends. The inside surfaces of the chambers are coated with a low-resistance conductive material, which adequately conducts image currents without significantly shielding the kickers' magnetic field [3]. Elevated temperatures are, however, measured on the flanges, vacuum chambers, and attached bellows during operation. Resistance measurements of this coating indicate that the coatings were inadequate or damaged, which lead to the increase in temperature [3].

Improvements in this design included detaching the bellows from the ceramic chamber. The chamber aperture, elliptical in shape, was reduced by 12.09 mm on the major axis and 2.65 mm on the minor axis, bringing it closer to the aperture of the SR vacuum chamber. The inside surfaces of the ceramic chambers were metallized with molybdenum (Mo-Mn) to an average thickness of approximately 10 μm .

4. Bellows and Liners

All bellows assemblies installed in the SR beam path are shielded from beam image currents and rf energy with finger-type spring contacts or a combination of spring contact fingers and rigid sleeve liners. These liners span the bellows convolutions, making contact with the mating rigid sleeve into which it slides as the bellows extends or compresses during bake-out. Various arrangements of liners are used to suit each type of bellows assembly. Figure 5 shows one type of bellows assembly where all surfaces of the contact finger and rigid sleeve are enclosed inside the SR vacuum. In comparison, the mating rigid sleeve for the contact spring fingers shown in Figure 6 is an integral part of the bellows assembly. The force generated by the deflection of the spring fingers creates the necessary contact between the rigid sleeve and the spring fingers. The design of the bellows and liners in the current kicker magnet chambers are such that they could not be hardened after they were brazed and they made very poor contact with the mating sleeve.

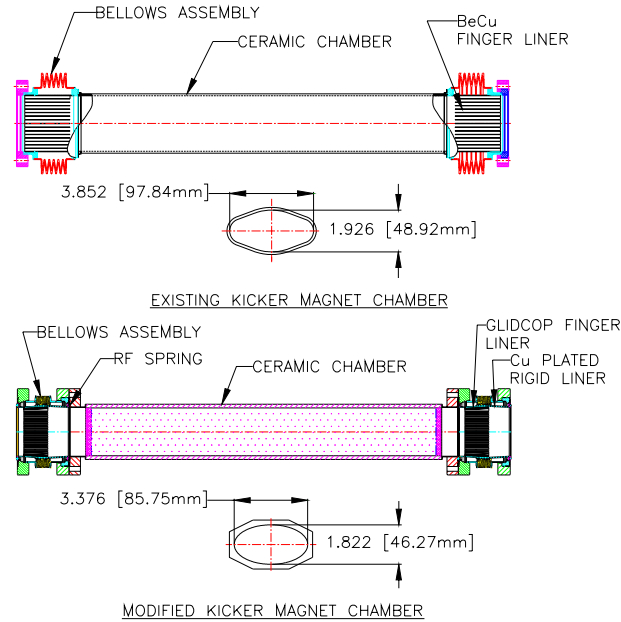


Fig. 4: Existing and modified kicker magnet vacuum chamber assemblies.

The following factors were considered and design changes made to improve the performance of the liners:

- Spring finger material:** The spring fingers are made from Be-Cu alloy because of its relatively high thermal and electrical properties and its high yield strength. However, Be-Cu has some disadvantages; it begins to soften due to annealing at 200 degrees Celsius [4], and it has to be hardened after brazing to improve its yield strength. Bellows temperatures are approaching this level when beam currents are increased to 140 mA. Finger liners in the current kicker magnet chambers are susceptible to droop, if they experience temperatures approaching 200 degrees Celsius for long periods in their annealed state. Here at the APS where we operate at 7 GeV for long runs, 160 degrees Celsius is a conservative set point for intervention before these liners fail. GlidCop AL-15 is the material of choice for the finger spring contact liners for the new bellows in the injection area.
- Heat transfer rate:** Heat transfer in vacuum is mainly by conduction. The sleeve of the rigid liner is made from 304 stainless steel. Its outer surface was plated with OFHC copper to improve the heat transfer rate.
- RF continuity:** To ensure adequate rf continuity, the depth of the groove that captures the rf coil spring and the depth at which the liner assembly is placed inside the face of the vacuum flanges are designed such that the spring is deflected when the flanges are locked to create a vacuum-tight joint
- Contact surface:** The rigid sleeve is made from stainless steel and in two halves, which are then welded. The weld build-up prevents some of the spring fingers from making good contact with the rigid sleeve along the weld seam. Making the part from one piece creates a much more even surface.

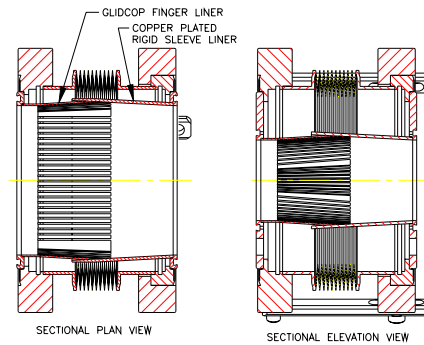


Fig. 5: Bellows assembly that uses a combination of rigid- and finger-type liners.

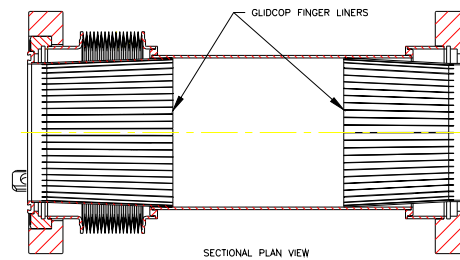


Fig. 6: Bellows assembly that uses finger-type liners only.

4.1 Liners

The rigid sleeve liner shown in Figure 7(a) is a brazed assembly of GlidCop to stainless steel using 35/65 Au/Cu braze alloy. The sleeve is a one-piece construction, made from type 304 stainless steel by the electrical discharge machining (EDM) process. A disk made from GlidCop AL-15 supports the rigid sleeve. The aperture in the disk is cut to the same shape and size as the aperture in the adjacent mating component to ensure a smooth transition between apertures. Also machined in the disk is a groove, into which is inserted a beryllium copper coil for rf continuity with the mating flange. After brazing, the outer surface of the stainless steel is copper plated with OFHC copper to an average thickness of 0.015 inch, to reduce the electrical resistance and increase the heat transfer.

The spring contact fingers, see figure 7(b), is constructed from 0.036-inch- thick GlidCop AL-15 sheets using the EDM process. The fingers are bent to a 3-degree angle and then formed into an elliptical shape similar to the SR beam tube aperture. An aperture identical to the adjacent mating component is machined into the supporting OFHC copper disk. This feature is again necessary to ensure a smooth transition between apertures of adjoining components. Both items are assembled and brazed with 35/65 Au/Cu braze alloy.

This new design varies from the existing designs with an increase in the bend angle from 2.5 degrees to 3.0 degrees on the fingers to create a greater contact force with the rigid sleeve. Some of the existing contact fingers were not solution hardened after brazing, so in the annealed state, their yield strength is further reduced with any increase in temperatures.

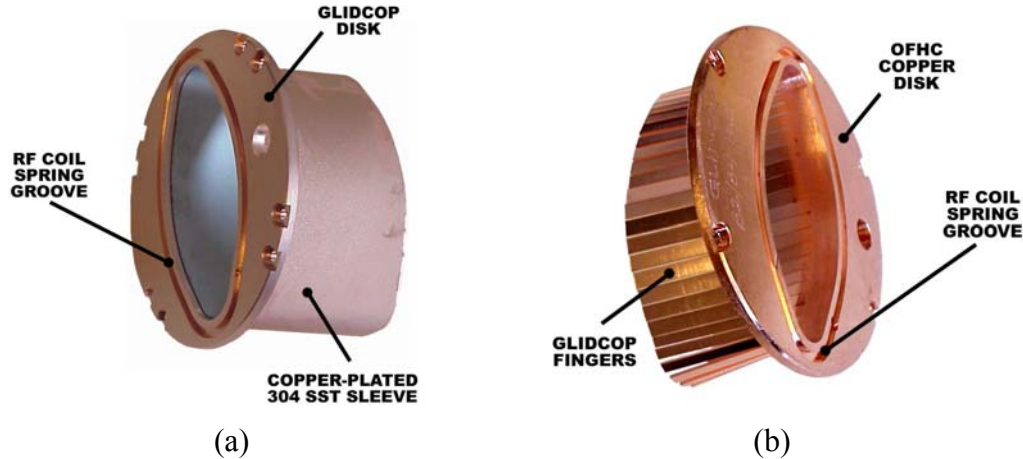


Figure 7: Bellows liners (a) rigid sleeve liner; (b) spring finger liner.

5. Impact on Machine Operation

The design changes made to the injection area components are expected to impact the machine operations in the in the following manner.

- Presently the ends of the ceramic vacuum chamber are convection cooled by a series of air blowers that require high maintenance. Based on the performance of similarly designed bellows in the rest of the SR, it is expected that the air blowers will be eliminated.
- Uniformity of the conductive coating on the inside surfaces of the ceramic chambers will reduce heating in the chamber walls and improve injection efficiency, especially in the top-up mode.
- It is expected that beam current in the SR can be increased to 300 mA without any increased heating problems in the injection area.
- New components in the injection area are modular. Future upgrading or replacement can be done individually, without substantial downtime.

6. Summary

Design changes made to the SR injection area components have been discussed. The kicker magnet ceramic vacuum chambers were redesigned with detached bellows and more uniform conductive coatings. Mechanical devices were added to allow for fixed ferrite and coil positions and the ability for repeatable positioning of the ferrite and coils.

GlidCop was used as the absorbing material in the transition absorbers and as bellows finger liners because of its high thermal and electrical properties and its stability at high temperatures. The placement of additional absorbers in the injection area protects vacuum components from x-rays.

The addition of a port on the mini-flag chamber provides for a screen to be inserted horizontally, which will allow for constant monitoring of the injected beam size and position.

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